ENERGY BALANCE IN THE MESOSPHERE AND THERMOSPHERE AS MEASURED BY SABER

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The SABER Science Team
• Today we will look at data from the NASA TIMED satellite and the SABER instrument that was launched over 14 years ago on 7 December 2001.

• This talk is possible only because in the late 1990’s, numerous engineers, project managers, resource analysts, and technicians did an excellent job of building and testing the TIMED instruments and satellite.

• This talk is dedicated to them, for the outstanding job they did, which provides all of us the privilege of doing science with the data.
Outline

• The Big Picture

• Overview of Thermosphere Energy Budget

• Radiative Cooling in the Thermosphere 2002 - present

• A View to the Past
  – Are different solar cycles more similar than different?

• Summary
The Big Picture....

• Major objective is to understand the climate and energy balance of the thermosphere

• This is a very complex interaction of radiative transfer, chemical/gas kinetics, energy storage, energy conversion, and solar physics

• We have learned over the past 14 years of observations from the TIMED satellite that the energy budget varies on time scales from a few days to decades

• This presentation summarizes some of the major results to date
Overview of the Thermosphere Energy Budget
Thermosphere Energy Balance – Thermal Structure

Banks and Kockarts, 1973
Thermosphere Energy Balance – Energy Inputs

External Energy Input
- Solar UV
- Solar Wind

Altitude (km)

Temperature (K)

Quiet Sun
Active Sun

Solar UV
Solar Wind

3/18/16
International Radiation Symposium - Auckland
Thermosphere Energy Balance – Energy Redistribution

Temperature (K) vs. Altitude (km)

- Energy Redistribution
- Heat Conduction
- Tides, Waves

Quiet Sun vs. Active Sun

3/18/16
International Radiation Symposium - Auckland
Thermosphere Energy Balance – Energy Outputs

![Diagram showing temperature vs. altitude for Quiet Sun and Active Sun scenarios.](image)

- **Energy Loss**
  - NO (5.3 µm)
  - CO₂ (15 µm)
Thermospheric Heat Sink

- Quiet Sun
- Active Sun
- Energy Loss
- NO (5.3 μm)
- CO₂ (15 μm)
- Tides, Waves
- Heat Conduction
- Energy Redistribution

Thermosphere Heat Sink Region

Temperature (K)

Altitude (km)
Radiative Cooling in the Thermosphere
Radiative Cooling in the Thermosphere

• Radiative cooling is the action of infrared radiation to reduce the kinetic temperature of the neutral atmosphere

• It is accomplished almost entirely by two species:
  – Carbon Dioxide (CO₂, 15 µm)
  – Nitric Oxide (NO, 5.3 µm)

• Collisions between atomic oxygen (O) and CO₂ and NO initiate the cooling process:
  – NO (ν = 0) + O → NO (ν = 1) + O  (Kinetic Energy Removal)
  – NO (ν = 1) → NO (ν = 0) + hν (5.3 µm)  (Kinetic Energy Loss)
  – NO (ν = 1) + O → NO (ν = 0) + O  (Kinetic Energy Returned)

• Collisional process are highly temperature dependent
Sounding of the Atmosphere using Broadband Emission Radiometry
-- SABER --

**SABER Experiment**

- Limb viewing, 400 km to Earth surface
- Ten channels 1.27 to 16 μm
- Over 30 routine data products including energetics parameters
- 8.3 million radiance profiles – per channel!
- Cryo-cooler operating excellently at 77 K
- Noise levels at or better than measured on ground
- Now in 15th year of on-orbit operation

- **Over 1200 refereed journal articles!**

75 kg, 77 watts, 77 x 104 x 63 cm, 4 kbs
NO and CO$_2$ Cooling Parameter Derivations by SABER

Measured Limb Radiance

Abel Inversion to Cooling Rate (W/m$^3$)

Cooling Rate for NO

Vertically Integrate Cooling to Flux (W/m$^2$)

Area integrate to get global power (W)
Sunspot and cooling maxima are not coincident
Strong semi-annual oscillation evident
Geomagnetic activity always evident in radiative cooling
SABER Global Power from NO in SC 24
Jan 2010 – Dec 2015; 100 – 250 km

Sunspot and cooling maxima not coincident
Each “spike” is the response to a geomagnetic event
St. Patrick’s Day Storm is largest event since 2010
SABER Global Power from CO$_2$
Jan 2002 – Dec 2015; 100 – 140 km

Over 5200 days of data!

Strong semi-annual cycle evident in global cooling
Evidence of response to geomagnetic activity in each “spike”
Over 5200 days of data!

SC 24 solar max (12/2014) as warm as 12/2003 – 11 years
SC 24 peak clearly weaker than SC 23

But, just how different in total energy are they?
NO Cooling at Peak of SC 24 (12/2014) was highest level since 12/2003

From the perspective of integrated energy, just how different is one solar cycle from another?
Fraction of Thermosphere Global Infrared Power
- CO$_2$ and NO -
A View to the Past
60-day Running Means – Nitric Oxide Power


![Graph showing the correlation between SABER Global NO Power, Ap Index, Dst Index, and F10.7 cm Solar Radio Flux with 60-day running averages.](image-url)
Multiple Linear Regression Fit
NO Power as Function of F10.7, Ap, Dst

Reconstruct cooling time series back to 1947 using extant F10.7, Ap, Dst
Multiple Linear Regression Fit
Power as Function of F10.7, Ap, Dst
Thermosphere Infrared Power Function of F10.7, Ap, Dst

Thermosphere Infrared Power (60-day Running Mean)

- Total
- CO2
- NO

Power (10^9 W)

Years: 1940 - 2020
Percent of Thermosphere Infrared Cooling

CO$_2$ and NO
Multiple Linear Regression Fit
Power as Function of F10.7, Ap, Dst

Thermosphere Infrared Power (60-day Running Mean)
Multiple Linear Regression Fit
Power as Function of F10.7, Ap, Dst

Thermosphere Infrared Power (60-day Running Mean)

<table>
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<th>Solar Cycle</th>
<th>NO Power</th>
<th>CO2 Power</th>
<th>Total Power</th>
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<td>6.51E+14</td>
<td>3.69E+15</td>
<td>4.34E+15</td>
</tr>
</tbody>
</table>
Summary

• SABER data illustrate a very complex and interesting thermosphere that responds to solar variability on timescales from days to decades

• Past 5 solar cycles vary show IR emission from atmosphere varies by at most 25% -
  – Are solar cycles more similar than different?

• Solar maximum, from the atmosphere’s perspective, does not have a consistent relationship to the sunspot number
  – Are new metrics for solar max/min for atmosphere response needed?